AE 755 COURSE PROJECT

Optimal drone deployment to maximize network coverage in uneven terrain

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Stage 1 Presentation

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PROBLEM STATEMENT

Finding the optimal location of drones such that maximum users in a given terrain can be provided with coverage, while ensuring

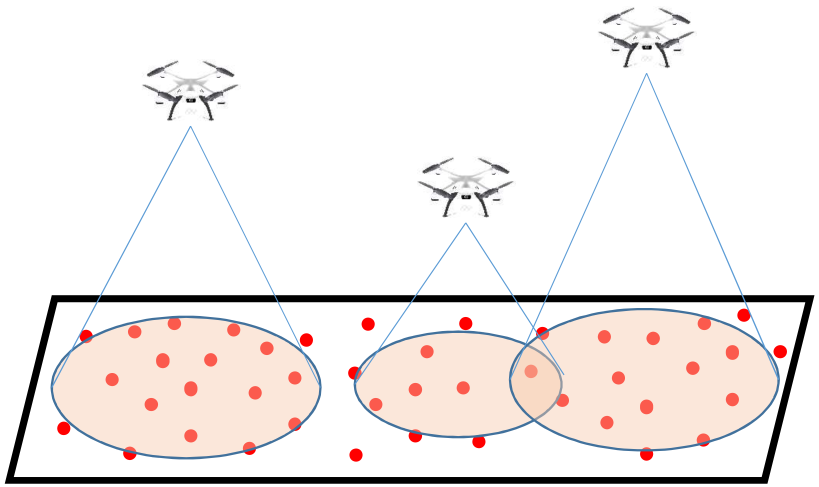
i. Quality of service to each connected user
ii. Operation within the capacity of each drone
iii. Connectivity between drones

Design Variables :

- (x,y,z) Position & Altitude of each drone

$$0 \leq x, y \leq 1000$$

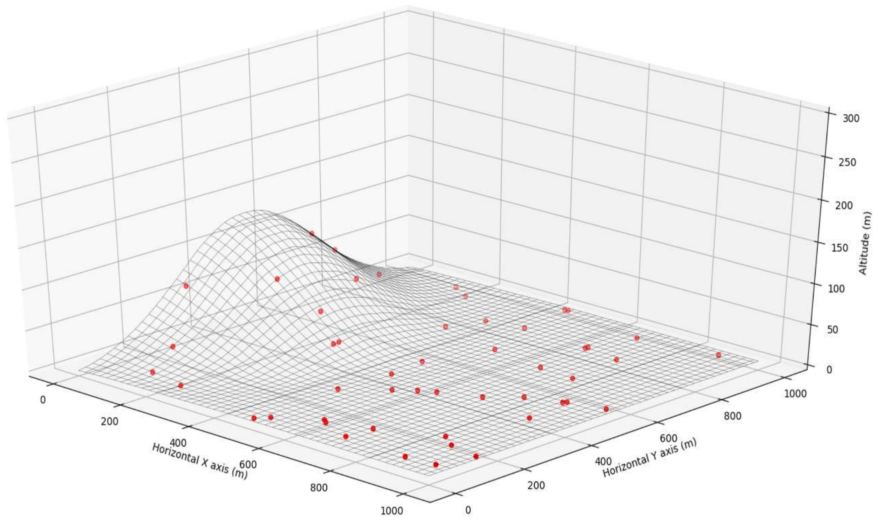
$$z_{terrain} \leq z \leq R_d$$



PROBLEM SETTING

Terrain specifications

- A 1000m x 1000m region has been selected with hilly features
- The region is assumed to be in an urban settling (to simulate path loss effects due to buildings and other structures)
- 50 Users have been randomly initialized in this terrain.



Drone specifications

- Bandwidth Capacity (C) : 10 Mbps
- Max bandwidth per user (B) : 1 Mbps
- Communication Frequency (f_c) = 2GHz

- Number of drones = 6

MATHEMATICAL DESCRIPTION

Objective Function

- Maximize No. of Users connected

$$u_i = \begin{cases} 1, & if\ it\ is\ connected\ to\ atleast\ 1\ drone \\ 0, & if\ it\ is\ NOT\ connected\ to\ any\ drone \end{cases}$$

$$\text{Minimize} \quad J = \begin{cases} -\sum_{i=1}^{N_U} u_i \ \ if\ N_c < N_U \\ \sum_{i=1}^{N_U} \sum_{j=1}^{6} PL_{i,j} \ \ if N_c = N_U \end{cases}$$

- Connection between the drone is established if the following conditions are met
  - ✓ Path Loss within acceptable limits ($PL_{i,j} \leq \gamma$)
  - ✓ Distance between User and Drone within communication radius ($d_{i,j} \leq R_d$)

MATHEMATICAL DESCRIPTION

Constraints

- Bandwidth capacity of each drone is not surpassed

$$\sum B_{i,j} \leq C_j$$

- Path loss between each drone and user is within expected values

$$PL_{i,j} \leq \gamma$$

- Each drone is within the communication radius of nearby drone

$$d_{i,j} \leq R_d$$

MATHEMATICAL DESCRIPTION

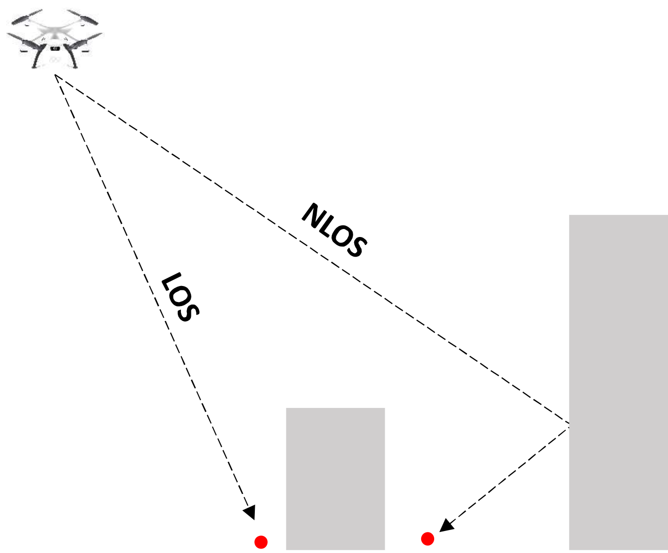
Path Loss Computation

- Path loss is a measure of reduction in power density of EM wave as it propagates through space

- Two types of Communications
    - Line of Sight (LoS)
    - Non-Line of Sight (NLoS)

- NLoS communication leads to higher path loss

- Probability of NLoS communication (P(NLoS)) is higher in high rise urban areas



$$\mathrm{P(NLoS)} = 1 - \mathrm{P(LoS)} \qquad P(\mathrm{LoS}) = \frac{1}{1 + a\exp(-b(\frac{180}{\pi}\theta - a))}.$$

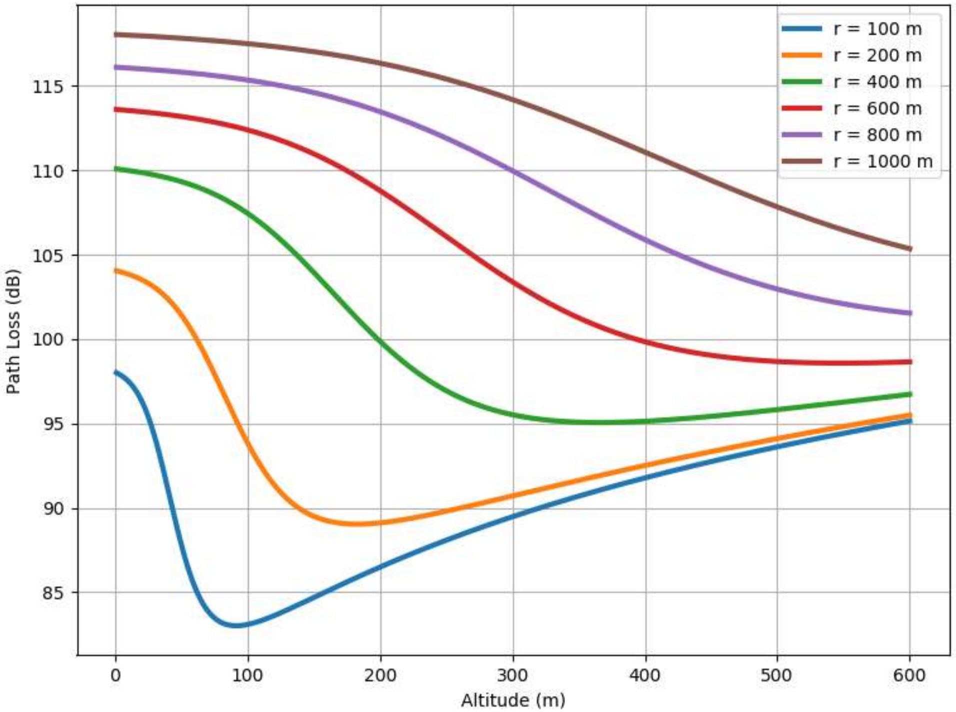
a, b : Environmental Constants
θ : Elevation Angle

MATHEMATICAL DESCRIPTION

- Using typical environment based path loss coefficients η_{LoS} & η_{NLo} , path loss can be computed as

$$\mathrm{PL} = 20\log\left(\frac{4\pi f_c d}{c}\right) + P(\mathrm{LoS})\eta_{\mathrm{LoS}} + P(\mathrm{NLoS})\eta_{\mathrm{NLoS}},$$

Path Loss vs Altitude for various horizontal distances



- For urban areas,

$$a = 9.61$$
$$b = 0.16$$
$$\eta_{LoS} = 1.0$$
$$\eta_{NLoS} = 20.0$$

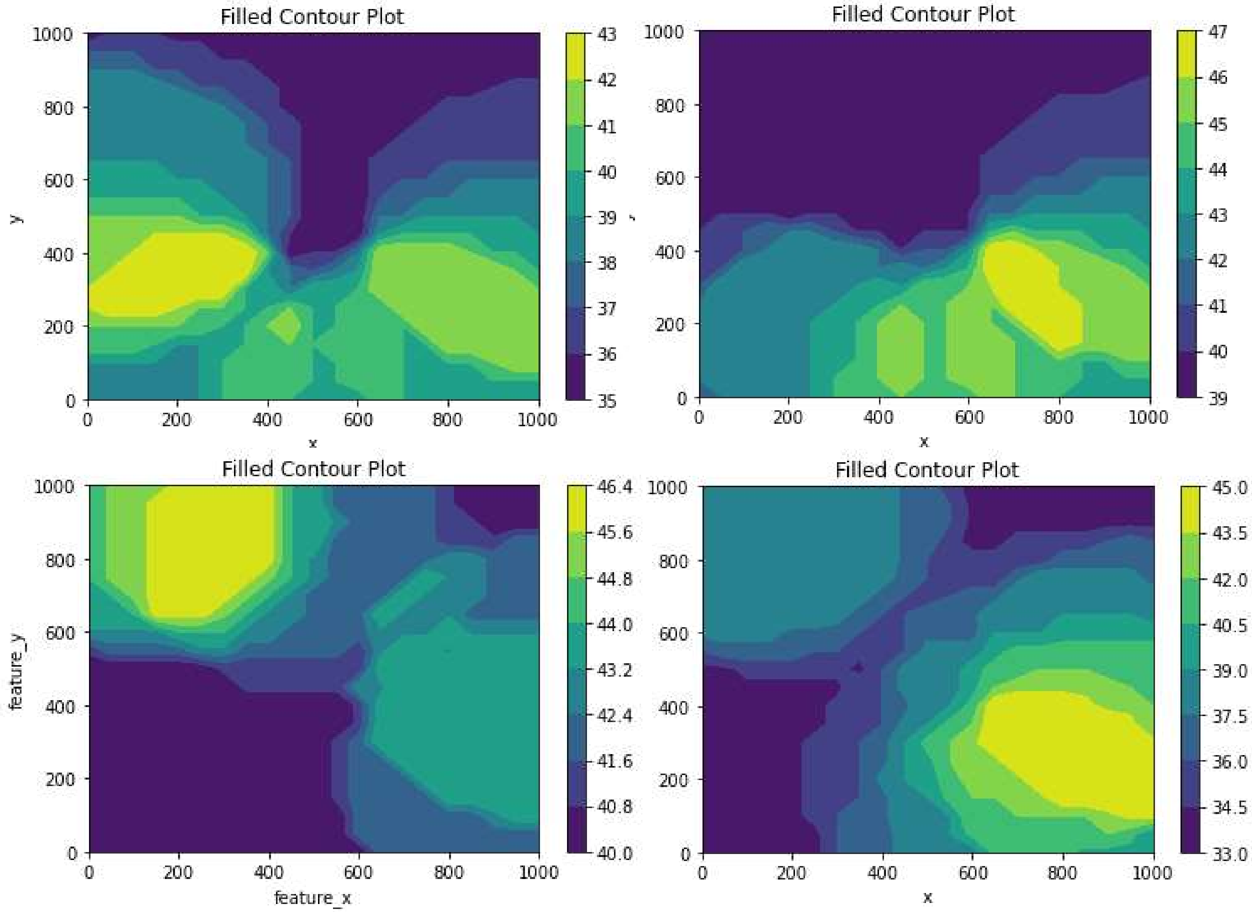
- Typical values of acceptable path loss in urban areas is 110 dB – 120 dB

DESIGN SPACE MAPPING

- The value of the objective function depends on the location of all the drones.

- Design space has been mapped using the following method
  - All drone locations have been randomly initialized
  - Individually, each drone is moved horizontally across the design space, while keeping all the other drones fixed
  - Value of the objective function is computed by checking the number of users that satisfy the connection requirements

- The design space is seen to be multimodal



SELECTION OF OPTIMIZERS

- From preliminary analysis, the design space appears non-convex
- Moreover, the objective function is non-differentiable. Hence, all gradient free techniques have been chosen for the project

❖ **Gradient Free Algorithms**

1. Particle Swarm Optimization
2. Differential Evolution
3. Genetic Algorithm

ADVANTAGES :

- **Initializes a large number of particles in the design space, and uses heuristics to attain a globally optimal solution**
- **Flexible in terms of scalability**
- **Adaptive mechanisms such as introducing trade-off between exploration and exploitation can be introduced**

RELEVANCE TO OUR PROBLEM :

- **Search space is multimodal in nature, a global search method ensures globally optimal solutions**

THANK YOU

ADDITIONAL SLIDES

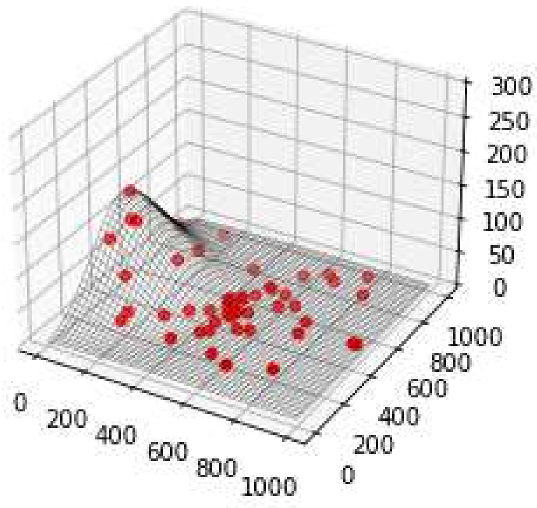
FUTURE PLAN

- **Development and Validation of optimizers**
  - Coding of algorithms in Python
    - Psuedocode & Python code
  - Validation with standard test functions

- **Integration of optimizer with project code (also in Python)**
  - Psuedocode & Python code

- **Benchmarking of results with available literature**

- **Implementation of developed algorithm on**
  - Different population distributions
  - Different terrain maps



Optimization Strategy

1. Conservative estimate on the number of drones (N_c) will be obtained
2. The optimum locations for N_c drones will be computed
3. Redundancy in the present solution will be determined
4. If redundancy exists,
   i. $N = N_c - 1$
   ii. Repeat Step 2 onwards
5. Else, Exit with the minimum number of drones required to provide coverage